Two neutron transfer in samarium isotopes and IBA model predictions

Saha, A; Scholten, O; Hageman, DCJM; Fortune, HT

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TWO NEUTRON TRANSFER IN SAMARIUM ISOTOPES AND IBA MODEL PREDICTIONS

A. SAHA [1], O. SCHOLTEN, D.C.J.M. HAGEMAN and H.T. FORTUNE [2]
Kernfysisch Versneller Instituut, Groningen, The Netherlands

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Marked inconsistencies in earlier data for two-neutron transfer strengths in the samarium isotopes make comparison with model predictions difficult. We compare here the results of a careful high-resolution (p, t) reaction study on ^{148,150,152,154}Sm at E_p = 40 MeV with IBA model predictions.

The stable samarium isotopes ranging from N = 84 to N = 90 encompass the region in which nuclei undergo a shape transition from vibrational to rotational. The interacting boson model (IBA) [1] predicts this change in the samarium isotopes in a natural and consistent way, and also explains rather well the energy levels and electromagnetic transition rates. As two-neutron transfer reactions are rather sensitive to the overlap of the wave functions of the target and residual nuclei, it seemed natural to test the predictions of the IBA model for two-neutron transfer reactions with those obtained from experiments.

Several investigations of (p, t) reactions and one study of (t, p) on the samarium isotopes have been reported [2–5], all at bombarding energies below 26 MeV. However, inconsistencies among the data make comparison with theory difficult. Even for g.s. → g.s. transitions, discrepancies in the existing data are larger than the A-dependent effects predicted. Thus, we have performed a careful high-resolution study of the (p, t) reaction on the samarium isotopes in order to compare the results obtained with IBA model predictions.

Isotopically enriched targets of ^{148,150,152,154}Sm were bombarded with 40 MeV protons from the KVI AVF cyclotron and the outgoing tritons were momentum analyzed and detected in the focal plane detection system of the QMG/2 magnetic spectrograph [6]. The total target thickness for each target was obtained by normalizing the measured elastic count rate in the angular range 20° to 35° (in steps of $2\frac{1}{2}$°) to the cross sections obtained from the optical model parameters of Becchetti and Greenlees [7] for 40 MeV protons. This method of estimating the target thickness introduced an absolute uncertainty of about 10%, but since the elastic data for all the targets were taken at the same time under identical conditions, the relative uncertainty is better than ±5%. Since the main source of error in the determination of the absolute differential cross section is the uncertainty in the measurement of the target thickness, we estimate the uncertainty for the absolute differential cross section for all the isotopes to be less than 10% and relative values to be within 5%. The g.s. cross sections we quote are for θ_{lab} = 14°.

The (p, t) spectra at θ_{lab} = 6° are displayed in fig. 1. The experimental energy resolution varied between 15 and 18 keV FWHM. Excitation energies listed on the (p, t) spectra were obtained from calibrations made by a least-squares polynomial fit to peaks having well-known energies. The results for each excitation energy were then averaged over at least six to eight angles. Standard deviations for the excitation energies are less than 5 keV for the strongly excited peaks.

The angular distributions to the 0^+ states are shown in fig. 2. The curves through the data points are results of L = 0 DWBA calculations using a cluster form

[1] Present address: University of Pittsburgh, Pittsburgh, PA 15260, USA.
[2] Present address: University of Pennsylvania, Philadelphia, PA 19104, USA.

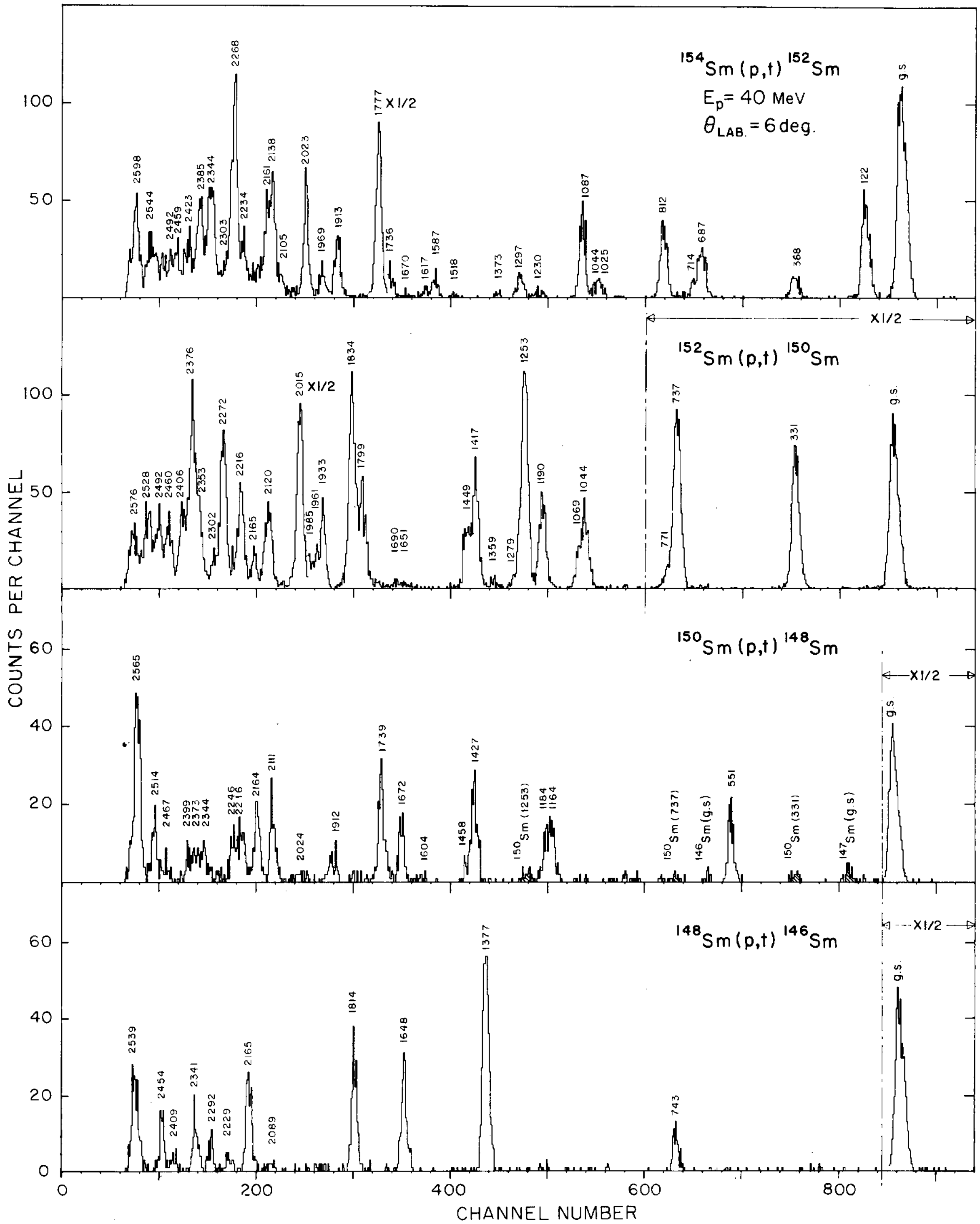

Fig. 1. Spectra of (p, t) reactions on various isotopes of Sm.

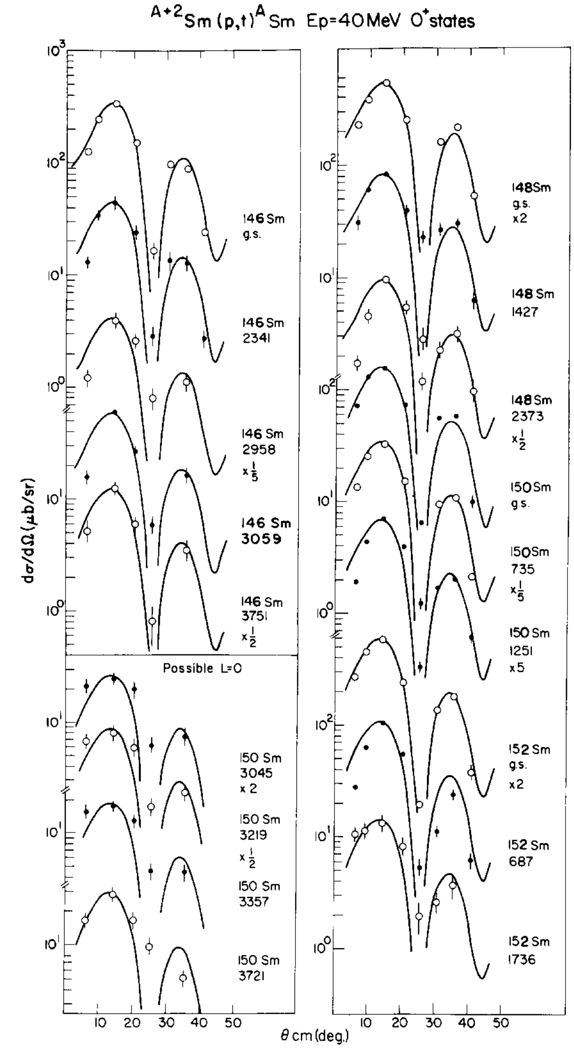

Fig. 2. Selected 0^+ angular distributions labeled by final nucleus and excitation energy (in keV).

factor for the transferred dineutron. Shapes with microscopic form factors are virtually identical. The optical model parameters used and given in table 1 are not very much different from those listed in ref. [8]. It should be emphasized that the DWBA calculations have been done primarily to take into account the Q-value effects before comparing with any model predictions. One of the main reasons for doing this experiment at E_p = 40 MeV is that the Q-value effects are rather small (±10%) over the range of isotopes and excitation energies studies and are also independent of the choice of optical model parameters [9].

The L = 0 shapes are rather unique and easily distinguishable from the other L-transfers. Several new 0^+ states have thus been identified at E_x = 2341, 2958, 3059 and 3751 keV in ^{146}Sm, E_x = 2373 keV in ^{148}Sm and E_x = 1736 keV in ^{152}Sm. Tentative 0^+ spin assignments are made to the states at E_x = 3045, 3219, 3357 and 3721 keV in ^{148}Sm and 1670 keV in ^{152}Sm. We observe no L = 0 strengths to states at E_x = 2611 keV in ^{146}Sm and E_x = 1923 keV in ^{148}Sm, which have previously been assigned 0^+ from other (p, t) [2–4] and (t, p) [5] experiments.

The relative strengths of transitions to the ground states and the first excited 0^+ states obtained in previous (p, t) experiments [2–4] and in this experiment are shown, in fig. 3, as functions of A. The strengths are normalized to 100 for the ^{148}Sm(p, t)^{146}Sm(g.s.). We immediately see that there are large discrepancies (over 50%) even in the g.s. strengths, especially for transitions to the ^{148,152}Sm g.s.

The Q-value effects have generally not been considered for the earlier experiments, but they are not large enough to explain the discrepancies. Our results agree with those of Oelert et al. [4] within experimental uncertainties for all except ^{152}Sm g.s. where we dif-

Table 1
Optical model parameters, (potentials in MeV, lengths in fm).

	V	r_0	a_0	W_V	$W' = 4W_D$	r_d	a_d	r_c
p	51.0	1.18	0.7		52.0	1.25	0.7	1.25
t	173.1	1.20	0.72	20.6		1.5	0.82	1.40
"2n" cluster		1.25	0.65					

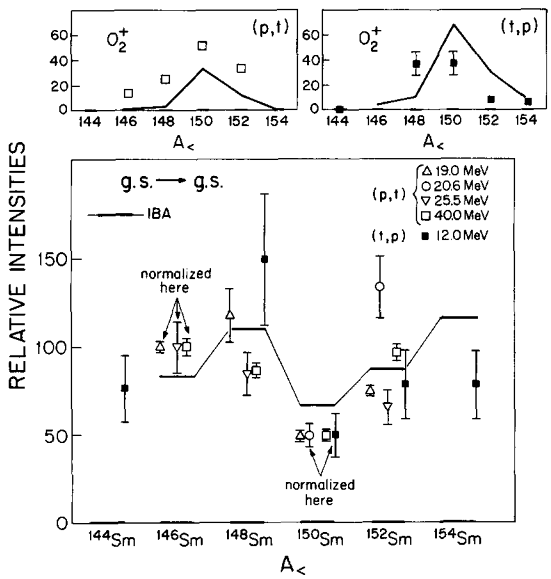

Fig. 3. (a) Experimental (dots) and calculated (line) (p, t) and (t, p) relative g.s. to g.s. cross sections. The (p, t) data are normalized to 100 for ^{148}Sm (p, t) ^{146}Sm. The (t, p) data are normalized to the (p, t) results for A = 150. (b) Experimental (dots) and calculated (lines) (p, t) and (t, p) relative cross sections for excited 0^+ states. The same scale is used as in fig. 3a. Note that A denotes the final nucleus for (p, t), but the target nucleus for (t, p).

fer by about 30%. Marked variations occur for the data of Debenham and Hintz [2] and McLatchie et al. [3] for ^{150,152}Sm even though they did their experiments at practically the same incident proton energy. Causes of these discrepancies are not apparent, but we believe our results reflect the true cross sections as practically all possible sources of uncertainties have been carefully monitored and accounted for. Only one investigation of the (t, p) reaction on the Sm isotopes has been reported – at E_t = 12 MeV by Bjerregaard et al. [5]. These relative strengths have also been plotted in fig. 3.

In the IBA model the (p, t) and (t, p) strengths can be calculated by assuming that the two-neutron transfer is a collective process. The two-nucleon pickup operator, T(p, t) for 0^+ states can be written as

$$T^{+(0)} = A_0 S_\nu (\Omega_\nu - \hat{N}_\nu)^{1/2},$$

where $2\Omega_\nu$ is the size of the major shell (in this case $2\Omega_\nu = 44$), and $\hat{N}_\nu$ is the boson number operator. For the two-nucleon stripping (t, p) reaction one has to take the hermitian conjugate of the above operator.

The IBA parameters describing the Sm nuclei were taken from ref. [1], in which excitation energies and B(E2) values are reproduced very well. The calculated ground-state cross sections are shown in fig. 3a. The parameter A_0 was determined by normalizing to an overall best fit. As was stated before there is a big discrepancy between the different measurements. The clear minimum in cross section observed for A = 150 is predicted by the IBA calculation, but the predicted increase in cross section when going from A = 146 to A = 148 is in contradiction with the present experiment.

In the calculation for the (p, t) and (t, p) strengths to excited 0^+ states there is no additional parameters For (t, p) the 0_2^+ strengths are reasonably well reproduced with the exception of ^{148}Sm where the calculated value is much too low. For (p, t) the strengths are underpredicted for all nuclei but the behavior with A, especially the maximum for ^{150}Sm, is reproduced very well.

In summary, new results for the (p, t) reaction on Sm isotopes remove many of the discrepancies present in earlier data. Calculations of the IBA type reproduce many of the observed features, but detailed agreement with 2n transfer strengths is only fair.

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